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Analysis of solar contribution evaluation method in solar aided coal-fired power plants

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Abstract

Solar aided coal-fired power plants utilize solar thermal energy for coupling coal-fired power plants in various types by using the characteristics of different thermal needs of the plants. In this way, the costly thermal storage system and power generating system will be unnecessary while the intermittent and unsteady of power generation will be avoided. Moreover, the aim of large-scale utilization of solar thermal power and the energy-saving will be realized. With the deep analysis of solar aided coal-fired power plants, the contribution evaluating system of solar thermal power needs to be explored. Five common evaluation methods of solar contribution are analyzed in this paper, and a 600MW solar aided coal-fired power plant is studied by these five methods comparatively. Therefore this study will supply the theoretical reference for the future research of evaluation methods and the subsidy policy of new energy.

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Keywords: solar thermal power generating, coal-fired power generating, solar contribution, evaluation methodology

1. Introduction

As a clean energy, solar energy has broad prospects. Presently, direct solar thermal power generation have been widely applied at home and abroad, such as solar parabolic trough power generation and solar tower power generation [1]. The high initial investment and lower thermal performance are huge obstacles to develop independent solar thermal power generation system [2]. Coupling solar energy with coal-fired power plant can achieve the large-scale utilization of solar thermal through coupling with different parts

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of the thermodynamic system [3]. In addition, the solar system is more secure and stable, while in direct solar thermal generation, the temperature must reach about 400 ℃[4].

After Gaggioli and EL – Sayed summarized the economic analysis method based on the second law of thermodynamics, the thermal economical analysis has gradually become an important method applied in the design, operation and transformation of energy system [5, 6]. At present, the thermal economics analysis on the integration of solar assisted coal-fired power generation system has been expanded gradually [7]. Suresh and Reddy have researched the subcritical and supercritical coal-fired units from the energy 、exergy、economy and environment[8]. Baghernejad and Yahoubi have analyzed the thermal economy of solar combined cycle system and put forward the optimization scheme through genetic algorithm [9].

In this paper, five evaluation methods are analyzed, and then, taking a 600MW solar aided coal-fired units as example, compared the five methods.

2. The introduction of solar aided coal-fired power plant

After adding solar energy, the combined system can be divided into power boosting mode and fuel saving mode [10].

3. Evaluation methods of the solar energy contribution

Five methods to evaluate the contribution of solar energy in solar aided coal-fired power plants are as follows:

3.1. From the collector field side, taking the solar heat as basis

Annual solar thermal generation N is calculated as follows:

$$N = \int m_{oil} c_p (T_{in} - T_{out}) \eta_{oil-hea} \eta_{ste} dt \tag{1}$$

Where, N is the solar thermal generation, t is the run time of complementary conditions, m_{oil} is the measured heat transfer oil flows, c_p is the thermal fluid heat capacity at constant pressure, T_{in} is the inlet temperature of heat transfer oil, T_{out} is the outlet temperature, $\eta_{oil-hea}$ is the efficiency of the water-oil heat exchanger, η_{ste} is the efficiency of pump steam cycle.

3.2. From the turbine side, taking the variation of main steam flow as basis

Annual solar thermal generation N is calculated as follows:

$$\mathrm{N}=\int_0^t (m_{ste,com} - m_{ste,coa}) \times (\mathrm{h}_{ste,in} - \mathrm{h}_{ste,out}) \eta_{com} dt \tag{2}$$

Where, $m_{ste,com}$ is the main steam flow of the complementary system, $m_{ste,coa}$ is the main steam flow before complementary, $h_{ste,in}$ is the main steam enthalpy entering the turbine, $h_{ste,\mathrm{out}}$ is the enthalpy outlet condenser, η_{com} is the complementary power efficiency.

3.3. From the coal side, taking the coal consumption as basis

Annual solar thermal generation N is calculated as follows:

$$\mathrm{N}=\int_0^t (\Delta \mathrm{B}_{coa,com} \times \mathrm{W}_{pow,com} \times \mathrm{Q}_{LHV} \times \eta_{coa}) \mathrm{dt} \tag{3}$$

Where, $\Delta B_{coa,com}$ is the saved coal consumption rate for complementary conditions, $\mathrm{W}_{pow,com}$ is the complementary conditions generation, Q_{LHV} is the low calorific value of coal, η_{coa} is the coal-fired power generation efficiency.

3.4. From the second law of thermodynamics, taking the thermal economics as basis

The cost of each exergy flow in subsystem i can be calculated by the consumption of the input exergy flow, namely:

$$C''_{i,j}=c''_{i,j}E''_{i,j}=E''_{i,j}(\sum c'_{i,j}E'_{i,j}+C_{ni})\Big/(n_{i,j}\sum E'_{i,j}) \tag{4}$$

Where, $C''_{i,j}$ is the exergy cost of output exergy flow j in subsystem i, $c''_{i,j}$ is the unit exergy cost of output exergy flow j in subsystem i, $c'_{i,j}$ $c'_{i,j}$ is the internal transfer price of output exergy flow j in subsystem i, C_{ni} is the non-energy cost in subsystem i.

3.5. From the experimental data, taking the experimental efficiency curve as basis

The calculation process of annual solar thermal generation $N_{sol-rea}$ is as follows:

$$N_{sol-rea}=Q_{sol}\times\eta_1\pm Q_{ste}\times(\eta_2-\eta_1) \tag{5}$$

Where, Q_{sol} is the integral of measured heat collection for one year, Q_{ste} is the heat of main steam, η_1 and η_2 are the complementary power efficiency curve and coal-fired power efficiency curve, +/- represents the steam turbine efficiency increasing/decreasing after the introduction of solar energy.

4. Case Study

According to Figure 1, two kind of systems (power boosting and coal saving) are carried by the Star-90 simulation platform. The main parameters are shown in Table 1 and Table 2.

Table 1 Major parameters of power increasing unit

Parameters	Value	Unit
Capacity	637.9	MW
Main steam parameters	24.2/566/566	MPa/℃/℃
Feedwater flow	1645.15	t/h
Condenser pressure	4.9	kPa
Feedwater temperature	289.45	℃
Coal consumption rate	226.44	g/kWh

Table 2 Major parameters of fuel saving unit

Parameters	Value	Unit
Capacity	600	MW
Main steam parameters	24.2/566/566	MPa/℃/℃
Feedwater flow	1563.975	t/h
Condenser pressure	4.9	kPa
Feedwater temperature	281.65	℃
Coal consumption rate	243.68	g/kWh

The simulation results of the five evaluation methods are shown in Figure 2.

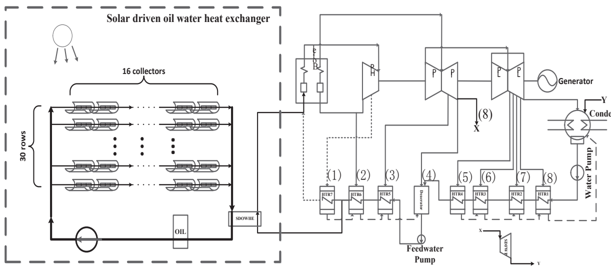

Figure 1 The layout of the solar aided coal-fired power plant

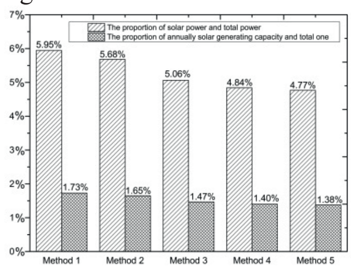

Figure 2 The simulation results of the five evaluation methods

Figure 2 shows that, for the same power system, the proportion of the solar thermal in total power through five different methods were 5.95%, 5.68%, 5.06%, 4.84% and 4.77%, the annual solar thermal generation accounts for the total electricity generation were 1.73% , 1.65% , 1.47% , 1.40% and 1.38%. For this case, the generation costs of coupling power plant is $ 0.21 / kWh and the solar share in coupled power plant is 0.67 % by using the method 4.

5. Conclusion

At present, there isn't a recognized method to evaluate the contribution of solar energy in solar aided coal-fired power station. In view of this five kinds of evaluation method, this article carried on detailed calculation and analysis. The results show that the method 4 is closer to actual plant operation data than method 1 and method 2 and method 3, and method 4 is more practical method 5, more, method 4 can also measure the increased generation cost in coupling plants due to the introduction of solar energy. Therefore, method 4 can reasonably evaluate solar contribution in solar aided coal-fired power stations, providing reliable reference for the establishment of feed-in tariff policy.

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Biography

Yong Zhu is a Ph.D. candidate in North China Electric Power University. His research interests focus on the development of solar thermal power generation, and analysis, optimization and integration of solar aided coal-fired power plants.